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RESEARCH MEMORANDUM

LOW-SPEED INVESTIGATION OF DEFLECTABLE WING-TIP ELEVATORS
ON A LOW-ASPECT-RATIO UNTAPERED 45° SWEPTBACK
SEMISPAN WING WITH AND WITHOUT AN END PLATE

By Jack Fischel and William M. O'Hare

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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NATIONAL ADVISORY COMMITTEE
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LOW-SPEED INVESTIGATION OF DEFLECTABLE WING-TIP ELEVATORS

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SUMMARY

A low-speed wind-tunnel investigation to determine the longitudinal control characteristics of deflectable wing-tip elevators on a low-aspect-ratio, untapered, 45° sweptback semispan wing was made in the Langley 300 MPH 7- by 10-foot tunnel. The elevators investigated had triangular and parallelogrammic plan forms and flat-plate profiles. These control surfaces were investigated on the plain wing and on the wing with a rectangular end plate (to simulate a vertical fin) mounted inboard of the elevators.

The results of the investigation indicated that deflectable wing-tip elevators compare favorably with conventional flap-type trailing-edge controls of the same area for producing longitudinal control on a swept-wing tailless aircraft.

The triangular wing-tip elevator was generally slightly more effective than the parallelogrammic wing-tip elevator. The end plate had only a slight effect on the effectiveness of either elevator plan form.

A comparison between experimental and estimated values of pitching moment produced by the deflectable wing-tip controls showed that their effectiveness could be predicted with reasonable accuracy at low angles of attack.

INTRODUCTION

The National Advisory Committee for Aeronautics is currently investigating various devices for use in providing adequate control on transonic and supersonic wing configurations. The deflectable wing-tip

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elevator is one of the longitudinal-control devices being considered and investigated for use on sweptback-wing tailless aircraft. This elevator consists of the entire tip of each wing and is deflected about a spanwise hinge axis approximately normal to the plane of symmetry.

A low-speed investigation conducted in the Langley 300 MPH 7- by 10-foot tunnel on a 45° sweptback semispan wing model showed that deflectable wing-tip controls provided adequate lateral control over the entire angle-of-attack range (reference 1). In order to determine the longitudinal control characteristics of deflectable wing-tip controls on a swept-wing model, lift, drag, and pitching-moment data obtained at various control deflections during the course of the investigation reported in reference 1 are presented herein. Parallelogrammic- and triangular-plan-form wing-tip elevators having flat-plate profiles and equal areas were investigated on the wing model through a large wing-angle-of-attack range and at elevator deflections up to 30° . The wing configurations had aspect ratios of 1.87 and 2.31 for the wing with the parallelogrammic-plan-form control and the triangular-plan-form control, respectively. These configurations were investigated with and without a large end plate (simulating a vertical fin) mounted on the wing inboard of the wing-tip elevators.

SYMBOLS

Inasmuch as the span of the wing equipped with the parallelogrammic and triangular wing-tip elevators differed appreciably (fig. 1), all data presented are based on the dimensions of the basic wing plus the control surface.

The forces and moments measured on the wings are presented about the wind axes, which, for the conditions of these tests (zero yaw), correspond to the stability axes. All three axes intersect at the intersection of the chord plane and the 25-percent-chord station of the mean aerodynamic chord at the root of the models (fig. 1).

The symbols used in the presentation of results are as follows:

C_L	lift coefficient (L/qS)
C_D	drag coefficient (D/qS)
C_m	pitching-moment coefficient ($M/qS\bar{c}$)
ΔC_m	incremental pitching-moment coefficient produced by elevator deflection

- \bar{c} wing mean aerodynamic chord (wing with parallelogrammic-plan-form elevator, 3.42 ft; wing with triangular-plan-form elevator, 3.36 ft) $\left(\frac{2}{S} \int_0^{b/2} c^2 dy \right)$
- c local wing chord, feet
- b twice span of each semispan model, including elevator (wing with parallelogrammic-plan-form elevator, 6.28 ft; wing with triangular-plan-form elevator, 6.97 ft)
- y lateral distance from plane of symmetry, feet
- S twice area of each semispan model, including elevator (21.02 sq ft)
- L twice lift of semispan models, pounds
- D twice drag of semispan models, pounds
- M twice pitching moment of semispan models about Y-axis, foot-pounds
- q free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2} \rho V^2 \right)$
- V free-stream velocity, feet per second
- ρ mass density of air, slugs per cubic foot
- α angle of attack with respect to chord plane at root of models, degrees
- δ elevator deflection, measured between wing chord plane and elevator chord plane (positive when trailing edge is down), degrees
- A wing aspect ratio (wing with parallelogrammic-plan-form elevator, 1.87; wing with triangular-plan-form elevator, 2.31) $\left(b^2/S \right)$
- $C_{m\delta}$ rate of change of pitching-moment coefficient with elevator deflection, at $\alpha = 0^\circ$ and $\delta = 0^\circ$ $\left(\partial C_m / \partial \delta \right)$
- d longitudinal distance along chord plane from center of moments of wing plus control surface to center of moments of wing-tip control surface alone, feet

CORRECTIONS

The angle-of-attack and drag data have been corrected for jet-boundary (induced-upwash) effects according to the methods of reference 2. Blockage corrections were applied to the test data by the methods of reference 3.

MODEL AND APPARATUS

The semispan wing model was mounted vertically in the Langley 300 MPH 7-by 10-foot tunnel with the root chord of the model adjacent to the ceiling (fig. 2), the ceiling thereby acting as a reflection plane. The wing, exclusive of elevators, was constructed of steel and mahogany to the plan-form dimensions shown in figure 1. The wing had NACA 64A010 airfoil sections normal to the wing leading edge and had neither twist nor dihedral. The wing tip was a body of revolution.

A vertical end plate which roughly approximated a vertical tail surface was mounted on the main part of the wing, inboard of the wing-tip body of revolution, for a portion of the investigation. This end plate was a $\frac{1}{2}$ -inch-thick sheet of plywood with rounded edges and was cut to the plan-form dimensions and mounted on the wing as shown in figure 1.

Two plan forms of wing-tip controls were used in the present investigation; one control surface had a parallelogrammic plan form, and the other a triangular plan form. Both control surfaces had equal root chords and equal areas (fig. 1) and were constructed of $\frac{1}{4}$ -inch sheet duralumin with a rounded leading edge and a 12° beveled trailing edge along the entire span of each control surface. The trailing edges of both control surfaces were swept back 45° . The elevators were deflected about a spanwise axis passing through the 0.5-tip-chord station of the wing and the 0.5-root-chord station of the elevator.

Although the elevators investigated did not have conventional airfoil sections, as would probably be the case in a practical application, the controls are believed to simulate an actual airplane arrangement sufficiently well to supply representative data.

TESTS

All tests were performed in the Langley 300 MPH 7- by 10-foot tunnel at a dynamic pressure of approximately 50.5 pounds per square foot, which corresponds to a Mach number of 0.19 and a Reynolds number of about 4.4×10^6 based on the wing mean aerodynamic chord. The aerodynamic characteristics in pitch were determined for the wing-elevator configurations with and without the end plate through an angle-of-attack range from positive to negative wing stall and at various control-surface deflections between 0° and approximately 30° .

DISCUSSION

Elevator Effectiveness of Deflectable Wing-Tip Controls

Lift, drag, and pitching-moment data obtained through the angle-of-attack range from tests of the 45° sweptback-wing model at positive deflections of the wing-tip elevators are presented in figures 3 to 6. In order to show the variation of pitching-moment coefficient with elevator deflection, the values of incremental pitching-moment coefficient ΔC_m obtained from figures 3 to 6 were cross-plotted against elevator deflection as shown in figure 7. Inasmuch as all wing-elevator configurations investigated were symmetrical and had symmetrical profiles (although the end plate was asymmetrically placed on the wing), the incremental pitching-moment data obtained at positive elevator deflections and negative angles of attack (figs. 3 to 6) were cross-plotted with opposite signs in figure 7 to provide data at negative elevator deflections and positive angles of attack.

In general, the data of figure 7 show that, in the negative deflection range, the elevator pitching effectiveness increased with increase in angle of attack; however, in the positive deflection range, the elevator effectiveness decreased with increase in angle of attack - particularly for angles of attack greater than about 8° . In addition, a reversal of effectiveness is exhibited at large positive values of α and δ by the wing-elevator configurations employing the end plate. This loss and reversal of effectiveness probably result from the stalling of the wing-tip control at large positive values of α and δ .

A comparison of the values of the slope of pitching-moment coefficient against elevator deflection $C_{m\delta}$ for the four configurations investigated is shown in the following table:

Elevator plan form	$C_{m\delta}$	
	Plain wing	Wing with end plate
Parallelogrammic	-0.0013	-0.0012
Triangular	-.0020	-.0020

In general, the data of this table and of figures 3 to 7 show that the triangular-plan-form elevator was more effective than the parallelogrammic-plan-form control over most of the deflection and angle-of-attack range. This effect results from the greater longitudinal moment arm between the aerodynamic center of the wing-tip control and the wing pitching-moment axis associated with the triangular-plan-form than for the parallelogrammic-plan-form elevator, and also from the larger aspect ratio of the triangular-plan-form control. The end plate on the wing generally had little effect on the elevator effectiveness, except as previously noted at large positive values of α and δ , where a greater loss in elevator effectiveness was exhibited by configurations employing the end plate. This slight effect of the end plate on the longitudinal control characteristics contrasts sharply with the sizable effect of the end plate on the lateral control characteristics of the same wing-control-surface configurations reported in reference 1. Thus, it appears that the end plate either affected only slightly the induction effects on the longitudinal control characteristics, or that the induction effects on the longitudinal control characteristics of all wing-control-surface configurations were generally small on the present wing.

In reference 1, it was noted that the wing-tip control in the presence of the end plate appeared to act essentially as an independent semispan wing, and, as such, the lateral control characteristics of the two plan forms of control surface were computed and were found to be in good agreement with experimental results. In order to determine the feasibility and the degree of accuracy of computing the elevator pitching effectiveness, values of ΔC_m were computed by the relationship

$$\Delta C_m = \frac{\text{Pitching moment of wing-tip elevator}}{qS\bar{c}}$$

$$d \left[\frac{(\text{Lift of wing-tip elevator}) \cos \alpha + (\text{Drag of wing-tip elevator}) \sin \alpha}{qS\bar{c}} \right]$$

for several elevator deflections and at various wing angles of attack. Values of lift, drag, and pitching moment of the wing-tip controls used in the preceding equation were obtained from references 4 and 5 for the wing plan forms most nearly comparable to the plan forms of the parallelogrammic and triangular elevators, respectively. The estimated values of ΔC_m thereby calculated are compared with test values of ΔC_m obtained with the end plate in figure 8 and, in general, are shown to be in reasonable agreement at small angles of attack. The poorer agreement exhibited between estimated and experimental values of ΔC_m at the larger angles of attack is attributed to the possible aerodynamic induction effects or interference effects caused by the wing-tip and elevator intersection. In addition, some discrepancy probably resulted because the plan form and section of the wing-tip controls investigated differed somewhat from those of the wings of references 4 and 5 for which data were used in the calculations of ΔC_m ; thus differences occur in the aerodynamic characteristics, particularly at large angles of attack. Because the calculations gave a good approximation to the test values of ΔC_m at low angles of attack and to the variation of ΔC_m with α and δ for the wing with the end plate, and because the end plate on the wing generally had little effect on the elevator effectiveness, it is thought that the elevator effectiveness of wing-tip controls, such as those of the configurations investigated, may be estimated by this procedure for preliminary design purposes.

Comparison of Elevator Effectiveness of Deflectable Wing-Tip

Controls and a 0.25c Trailing-Edge Flap-Type Control

In order to determine the relative effectiveness for a tailless airplane configuration of the wing-tip controls investigated, deflections of the wing-tip controls required to trim values of C_m of 0.04 and -0.04 through a large range of lift coefficients are compared in figure 9 with the values of δ required to trim similar values of C_m of an unsealed 0.25c flap-type trailing-edge elevator on the same wing. It should be noted that the comparisons shown in figure 9 are purely illustrative, but the relative effectiveness of the various controls is expected to be similar for other values of C_m . The data presented for the flap-type trailing-edge elevator were obtained by interpolating unpublished experimental data for 0.25c plain flaps of various spans on the present wing (excluding the wing-tip controls) in order to provide data for a 0.25c flap having the same area as each of the wing-tip controls.

The data of figure 9 show the conventional flap-type control to be more effective than either of the wing-tip controls at positive (down) elevator deflections. At negative (up) elevator deflections, however,

the flap-type control is seen to lose effectiveness rapidly with increase in lift coefficient so that the triangular wing-tip control is more effective than the flap-type control over almost the entire lift range and the parallelogrammic wing-tip control is more effective than the flap-type control at high lift coefficients. Because negative elevator deflections are usually used in flight for trimming the airplane and for maneuvering - particularly in take-off and landing - and only small positive elevator deflections are sometimes required, the significance of these effects can readily be realized. Moreover, the comparison presented is for low-speed data and does not show the effects of Mach number on the relative effectiveness of the various control surfaces. References 6 and 7 and unpublished data show that the effectiveness of each of the controls considered should increase with increase in Mach number up to high subsonic speeds. These data also show, however, that the effectiveness of the conventional flap-type elevator generally decreases measurably in passing through the transonic region and is much lower at supersonic speeds than at subsonic speeds, whereas the effectiveness of the tip controls generally is only slightly affected in the critical transonic region and is almost as good at supersonic speeds as at subsonic speeds. In addition, the data of references 8 to 10 and unpublished data indicate that the hinge moments of conventional flap-type controls probably will be extremely difficult to balance aerodynamically over the speed range from subsonic to supersonic speeds, whereas the hinge moments of the tip controls - and particularly the triangular tip control - may more easily be closely balanced over the entire speed range. Thus, deflectable wing-tip controls seem to compare favorably with conventional flap-type trailing-edge controls (of the same area) for producing low-speed longitudinal control on a swept-wing tailless aircraft and should compare even more favorably at high speeds than the present data show. In addition, because deflectable wing-tip controls were shown to produce adequate lateral control for deflections of 30° to -30° (reference 1), it is thought that they may be used as elevons (or ailerons) to produce both longitudinal and lateral control on swept-wing tailless aircraft.

CONCLUSIONS

A low-speed investigation of triangular- and parallelogrammic-planform deflectable wing-tip elevators on a low-aspect-ratio, untapered, 45° sweptback semispan wing with and without an end plate (simulating a vertical fin) was performed in the Langley 300 MPH 7- by 10-foot tunnel. The rectangular end plate was mounted on the wing just inboard of the elevators. The results of the investigation led to the following conclusions:

1. Deflectable wing-tip elevators compare favorably with conventional flap-type trailing-edge controls of the same area for producing longitudinal control on a swept-wing tailless aircraft.

2. The triangular-wing-tip elevator was generally slightly more effective than the parallelogrammic-wing-tip elevator.

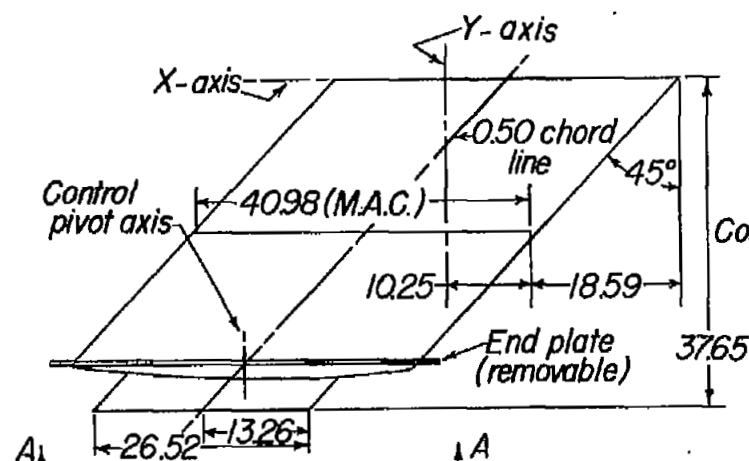
3. The end plate had only a slight effect on the effectiveness of either elevator plan form.

4. A comparison between experimental and estimated values of pitching moment produced by the deflectable wing-tip controls showed that their effectiveness could be predicted with reasonable accuracy at low angles of attack.

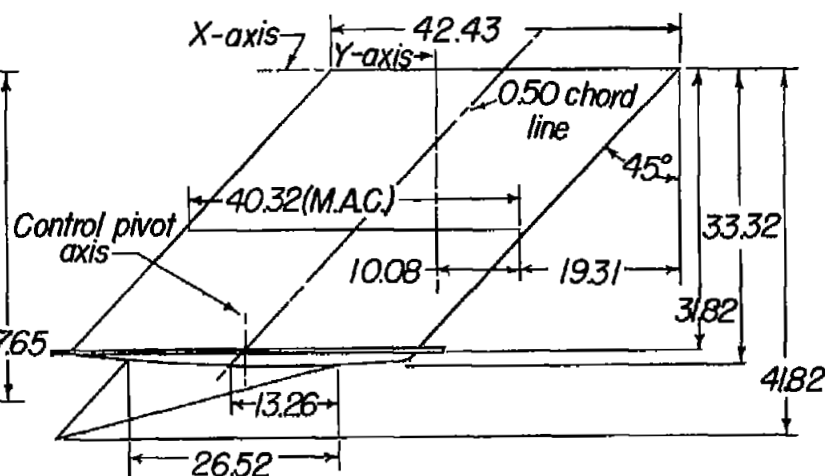
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National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

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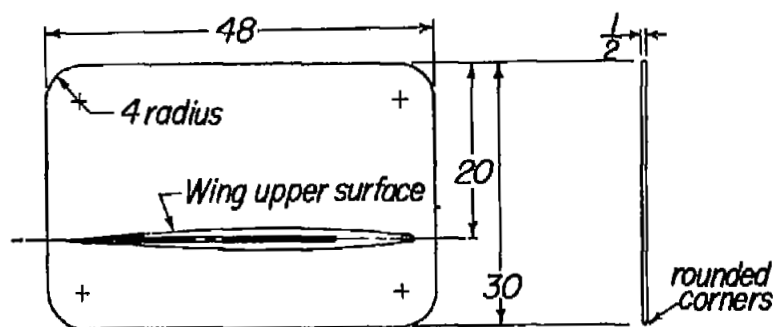
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Wing with parallelogrammic tip control.



Wing with triangular tip control.



End plate
View A-A

Areas

Complete wing
with parallelogrammic tip control 21.02 sq ft
with triangular tip control 21.02 sq ft
End plate (on both wing semispans) 20.00 sq ft

Aspect ratio

Wing
with parallelogrammic tip control 1.87
with triangular tip control 2.31

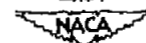
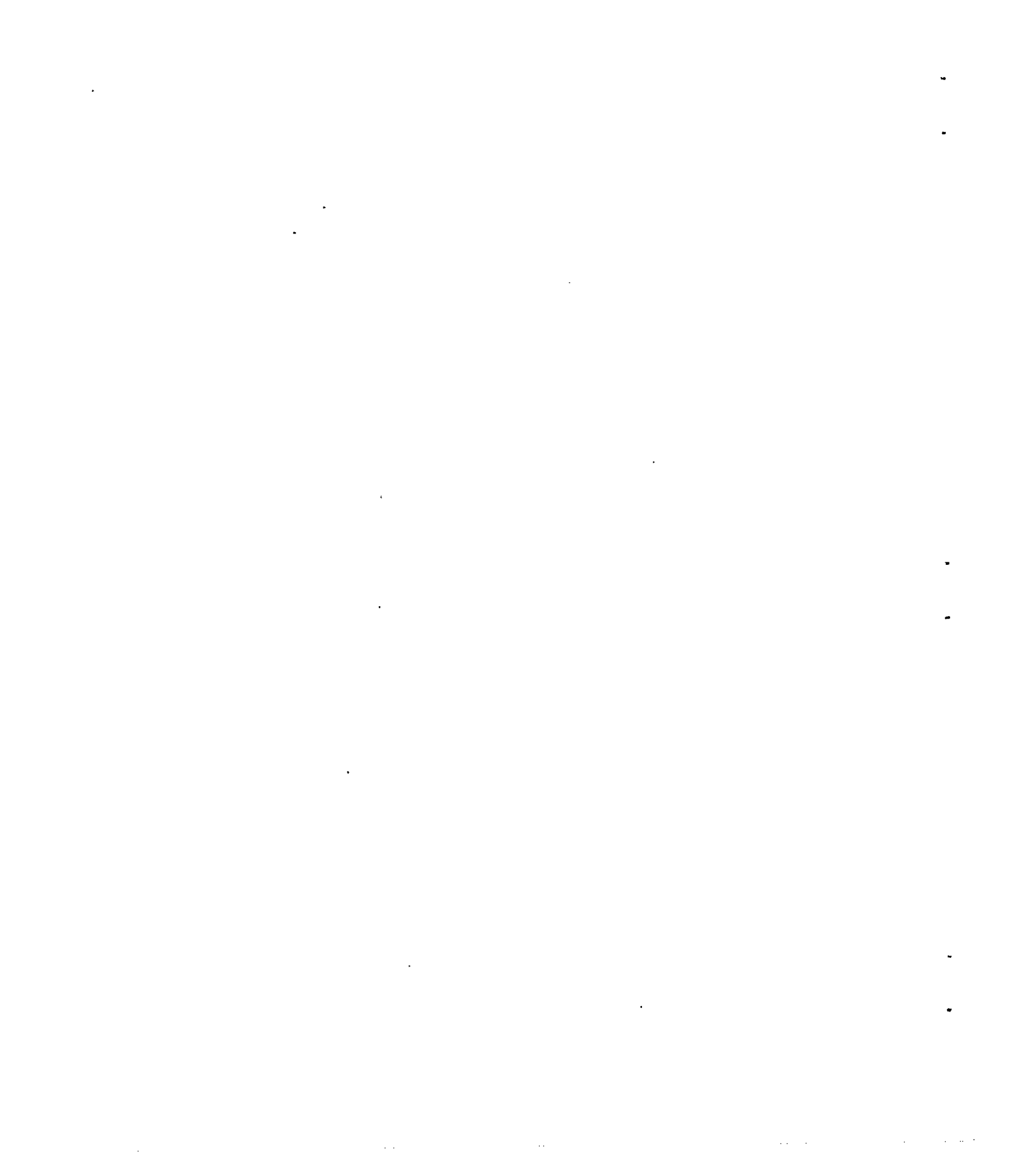


Figure 1.- Geometric characteristics of the 45° sweptback wing, wing-tip controls, and end plate. (All dimensions in inches unless otherwise noted.)



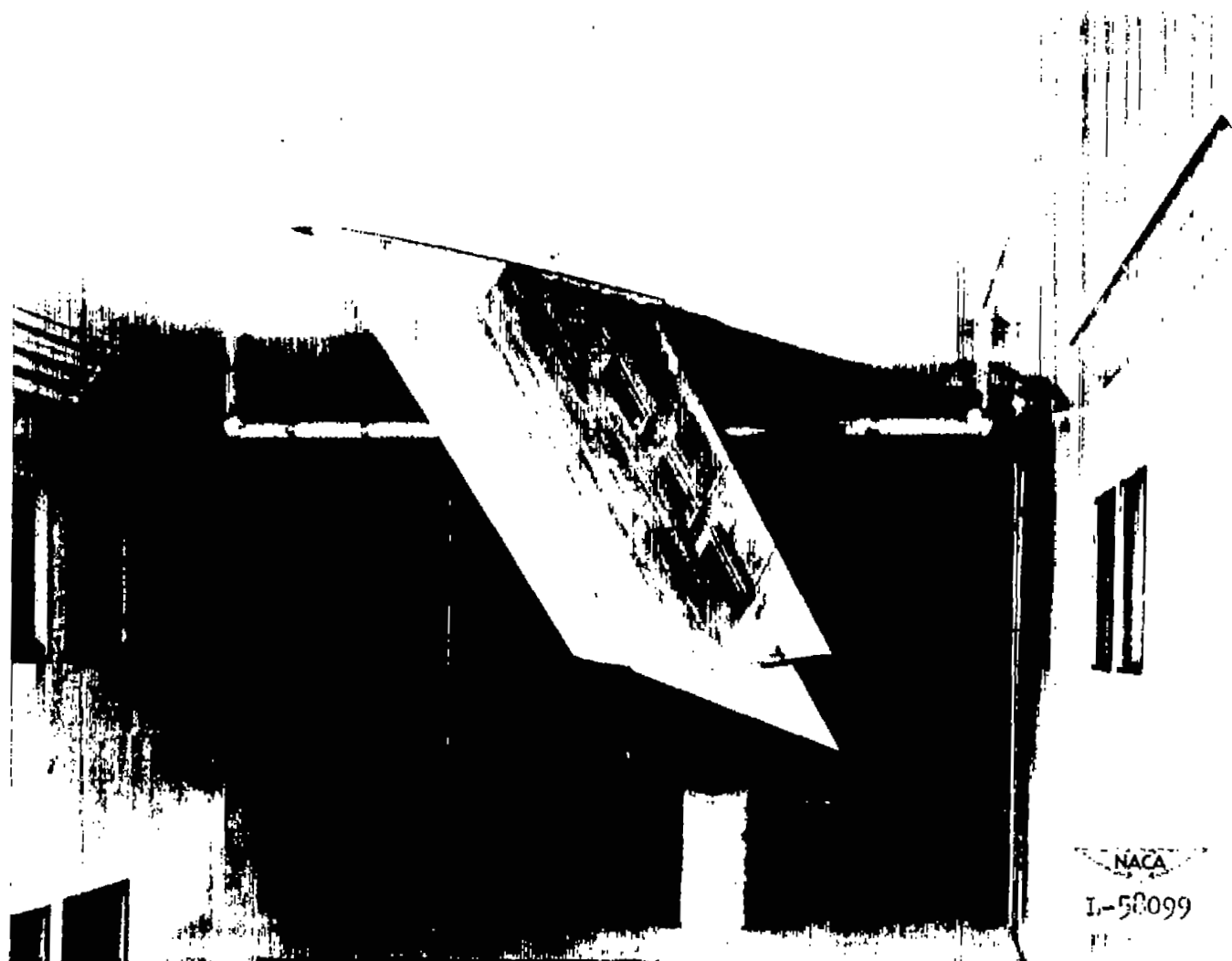


Figure 2.- The 45° sweptback semispan wing mounted in the Langley 300 MPH
7- by 10-foot tunnel. Plain wing with triangular wing-tip elevator.

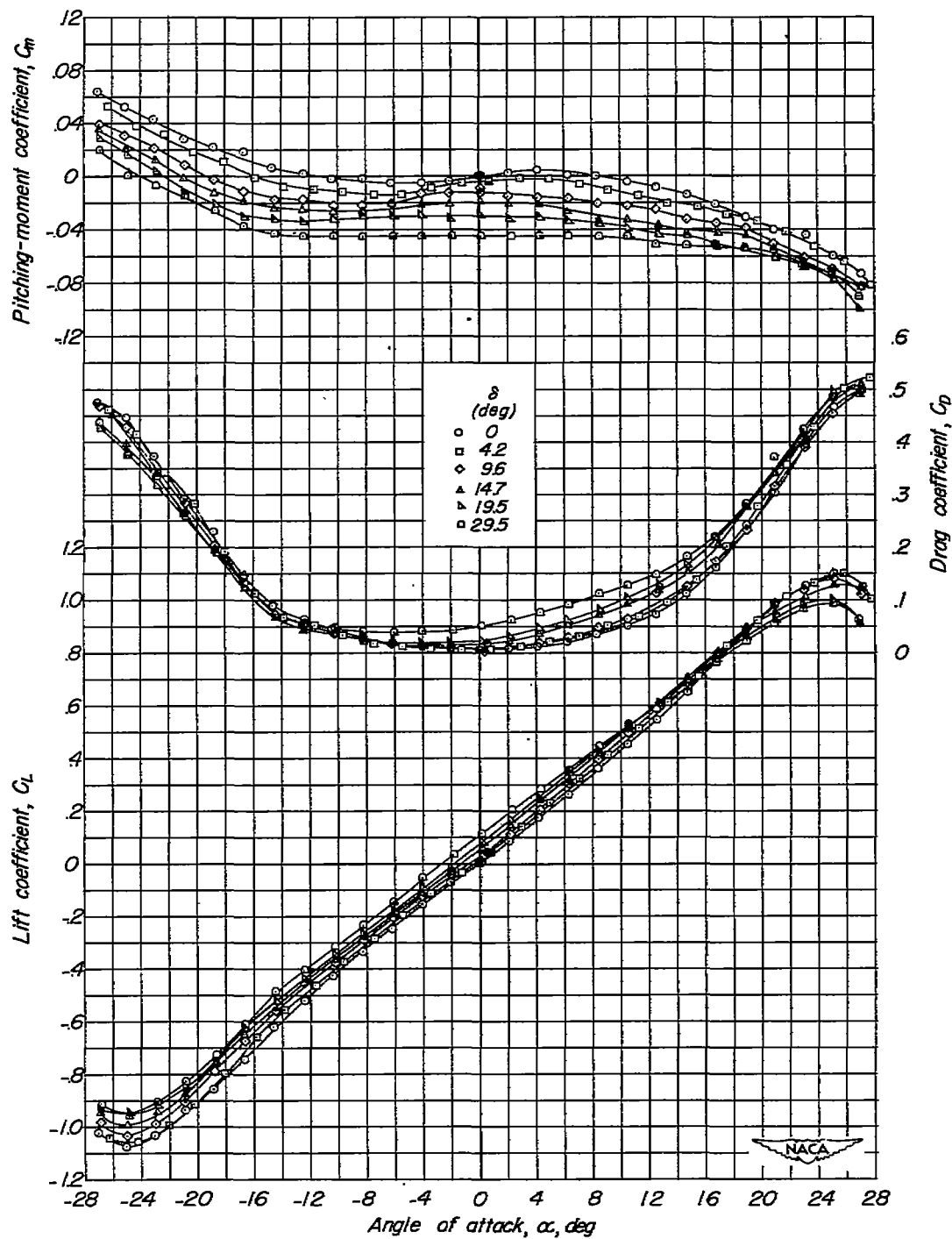


Figure 3.- Aerodynamic characteristics of the 45° sweptback wing for various deflections of the parallelogrammic wing-tip elevator. Plain wing.

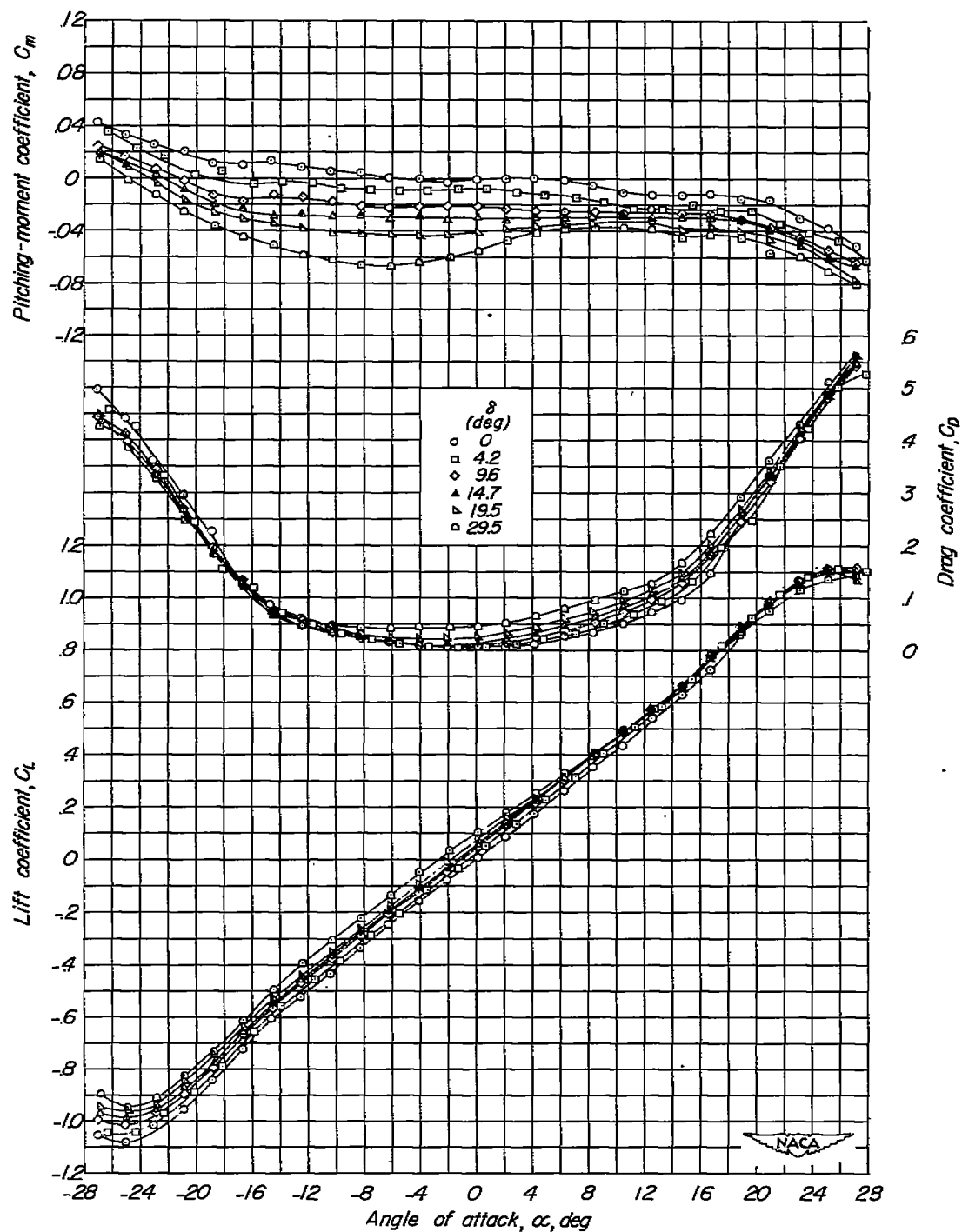


Figure 4.- Aerodynamic characteristics of the 45° sweptback wing for various deflections of the triangular wing-tip elevator. Plain wing.

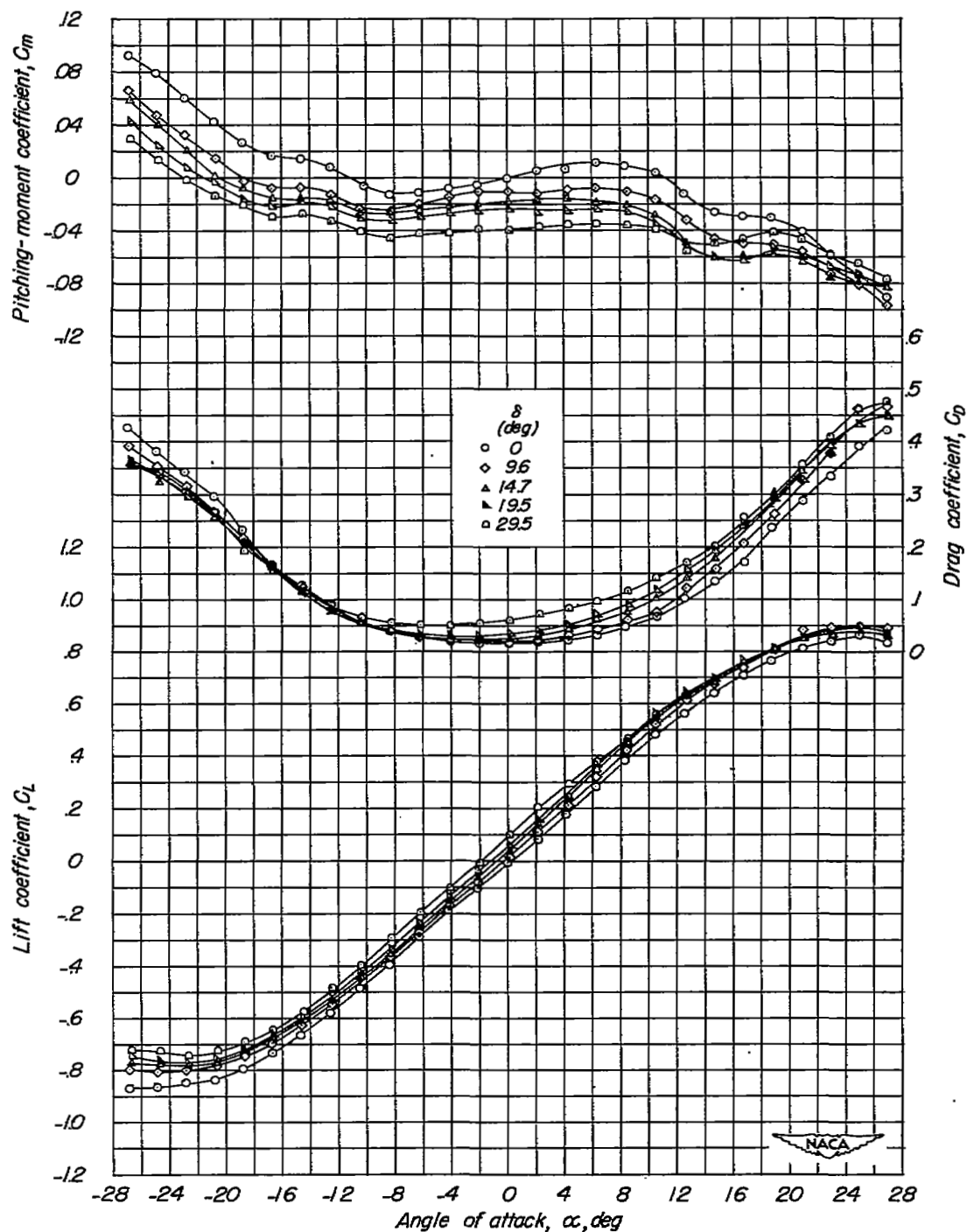


Figure 5.- Aerodynamic characteristics of the 45° sweptback wing for various deflections of the parallelogrammic wing-tip elevator. Wing with end plate.

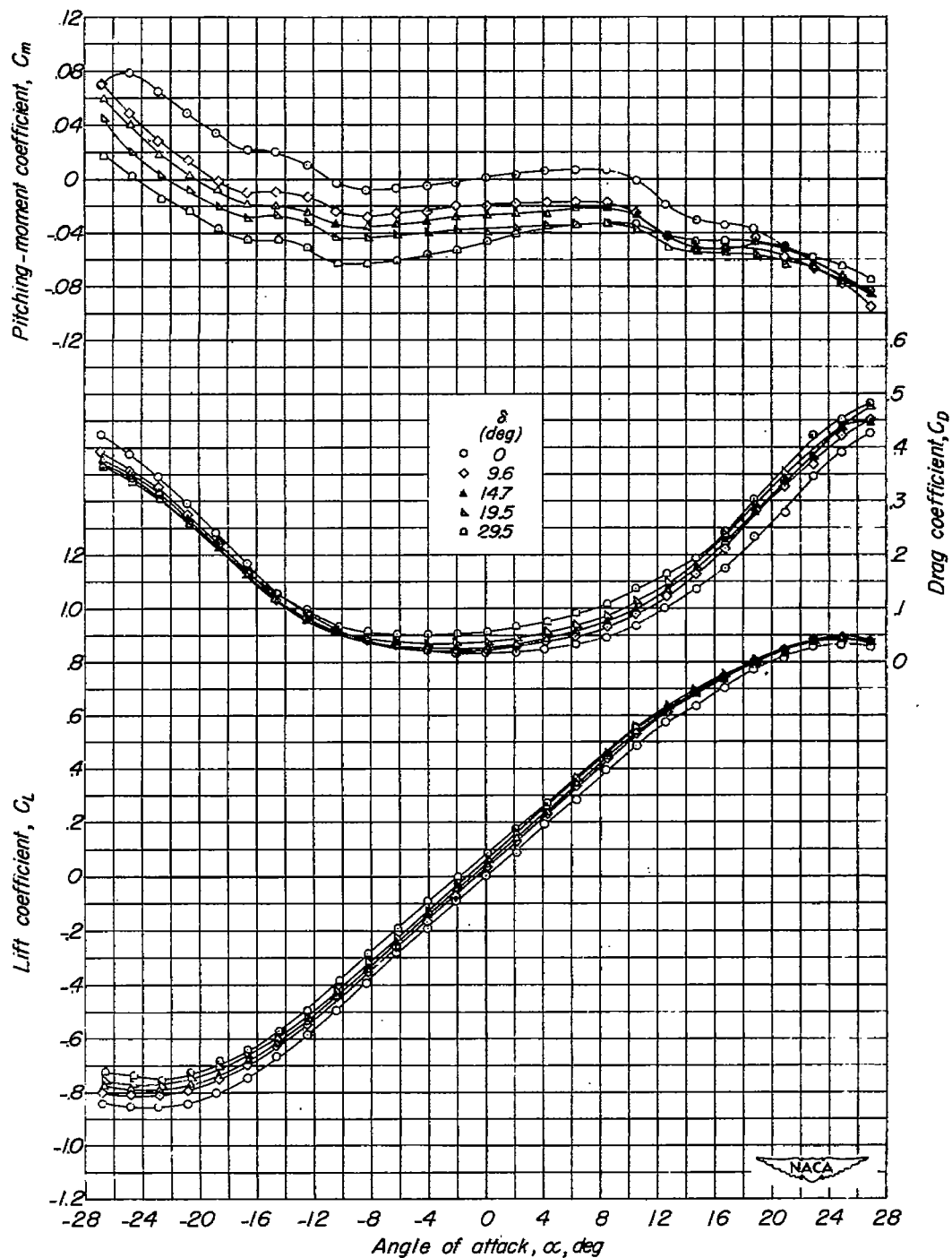


Figure 6.- Aerodynamic characteristics of the 45° sweptback wing for various deflections of the triangular wing-tip elevator. Wing with end plate.

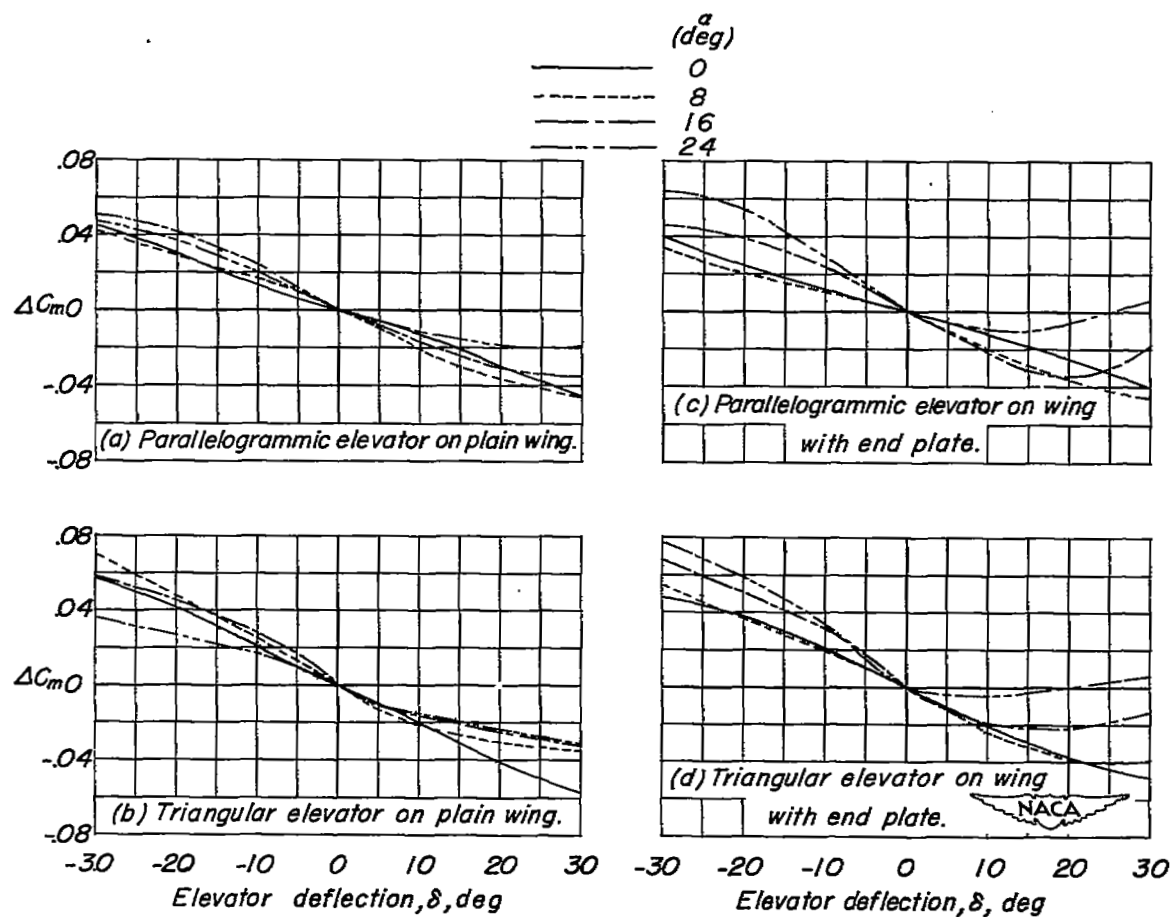


Figure 7.- Incremental pitching-moment coefficients produced by wing-tip elevators on the 45° sweptback wing.

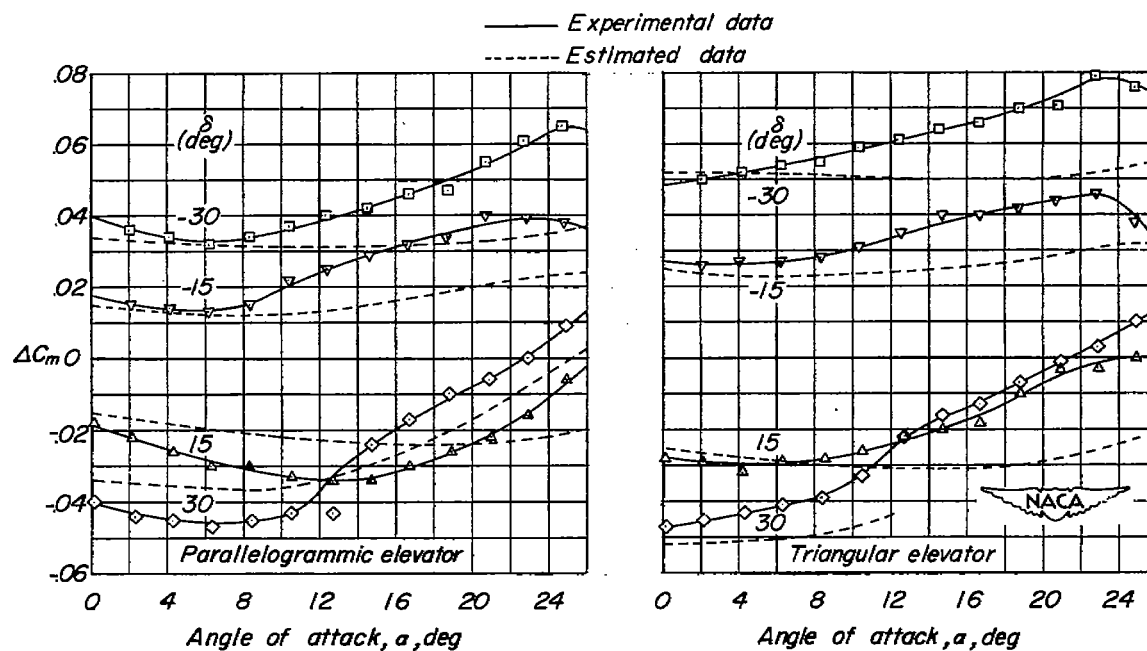


Figure 8.- Comparison of experimentally determined values of ΔC_m with estimated values of ΔC_m for deflectable wing-tip elevators in the presence of an end plate.

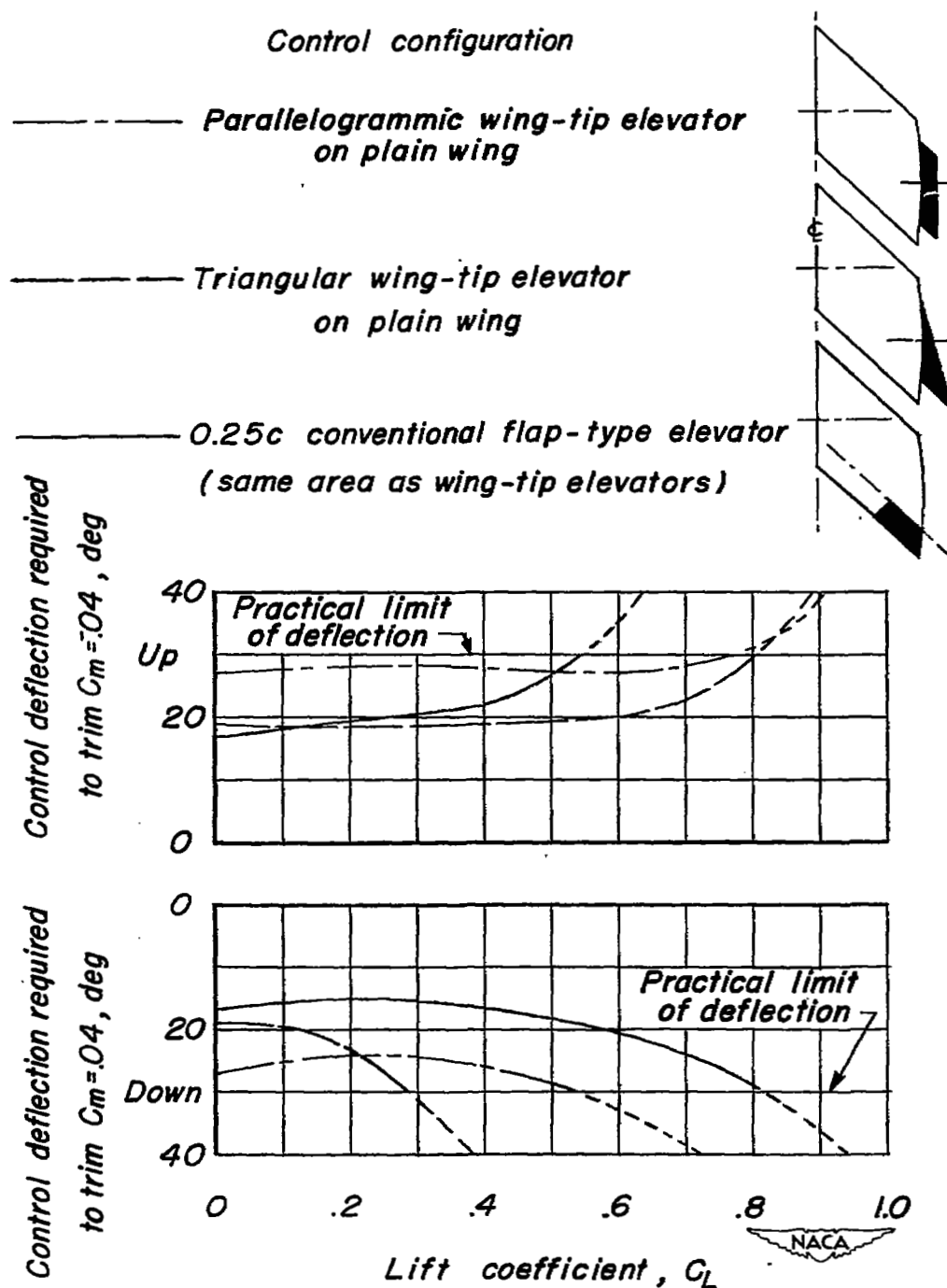


Figure 9.- Comparison of elevator effectiveness of wing-tip elevators and a 0.25c flap-type trailing-edge elevator on a 45° sweptback wing.